

PLANT WATER RELATION

SOIL

Definition: Soil is a dynamic natural body developed as a result of pedogenic processes during and after weathering of rocks, consisting of mineral and organic constituent, possessing definite chemical, physical, mineralogical and biological properties, having a variable depth over the surface of earth and providing medium for plant growth of land plants.

Condition of Weathering:

Physical - Temperature, Air current & Rain water.

Chemical - Acid-Base Reaction.

Nature of Soil depends on:

1. Texture: a) Colour, b) Roughness
2. Size of the soil particles:

Size	Type
<0.002 mm.	Clay
0.002 - 0.02 mm.	Silt
0.02 - 0.2 mm.	Fine sand
0.2 - 2 mm.	Coarse sand
2 - 5 mm.	Fine gravel
>5 mm.	Coarse gravel

Major Type of Soil:

Loam = Clay: Silt: Sand = 1:1:1

Clay - Loam = Predominance of sand

Sandy Loam = Predominance of clay

Constituent of Soil:

1. Physical:

Soil Water

i) Gravitational Water (free water): Which remain within the soil for a very brief period and not available to the plants.

ii) Capillary Water - After the removal of the gravitational water, the water present in the capillary surface between soil particles are called capillary water.

iii) Hydroscopic water - The water which remains attached with the soil particles due to surface tension is called hydroscopic water. It is also not available to plants.

iv) Combined water- When water remain combined with the mineral salts, like $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ which is not available to plants too, is called combined water.

Water holding capacity = All soil water - Gr. w.

= Cap. w. + Comb. w. + Hy. w.

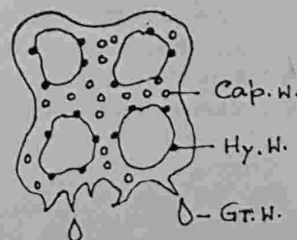
Water storage capacity = Water holding capacity - water not available to plant

= Cap. w.

Holard - Total water present in the soil.

Cherasard - The amount of water available to plant.

Echard - Non available water



✓ WATER POTENTIAL

✓ The term water potential was coined by Slatyer and Taylor (1960). Water potential is a term used in place of DPD by recent physiologists. It is equal in magnitude to DPD but opposite in sign. Water potential of pure water is zero, which is a maximum. The water potential for solution is less than 0, i.e. in negative value.

As DPD is the difference of diffusion pressure between the pure solvent and solution the water potential is a difference between the free energy of water molecules in pure water and that of water in any other system (solution). Water potential is chemical potential of water. Chemical potential is free energy per molecule or per gram at constant temperature and pressure (e.g. calorie/mol). Free energy in chemical species is produced due to kinetic energy of chemical substances. Kinetic energy is produced due to movement of particles in available space randomly, with a tendency to be distributed throughout the available space. It also depends upon number of particles per molecule. Higher the collision between molecules/particles, higher the kinetic energy: higher the kinetic energy, higher the free energy

Free energy of a chemical species can be derived from the formula:

$$G = E + Pv - Ts$$

Where, E = internal energy

P = Pressure

V = Volume

S = entropy (extent of disorder)

G = Free energy

T = Absolute temperature

Internal energy depends upon its chemical nature. The chemical nature includes the fashion in which molecules are put together, the nature of individual atoms, arrangement and number of electrons and the energy possessed by nucleus.

Direction of flow of free energy i.e. flow of water, is determined by the concentration of free energy. It is from higher free energy to lower free energy i.e. from high water potential to low water potential.

Absolute values of water potential are not easily measured but differences in water potential can be measured between system under investigation (plant tissue) and that in reference state (pure liquid water at constant temperature and pressure). Water potential for pure water is arbitrarily fixed as zero at particular atmosphere (2 atmospheres) and temperature. However, deviations from this value can be ascertained.

Components of Water Potential: Water potential has three components:

i) Solute potential (ψ_s)

ii) Matrix potential (ψ_m)

iii) Pressure potential (ψ_p)

Solute potential and matrix potential together constitute osmotic potential (ψ_π). ψ_π is the potential with which pure water will diffuse towards a solution. Water potential is equal to the algebraic sum of all the above components, i.e.,

$$\psi_w = \psi_s + \psi_m + \psi_p, \text{ Where } \psi_w = \text{water potential}$$

Water potential depends on matrix potential, solute potential and pressure potential. When a cell is subjected to the movement of water, these factors operate simultaneously and determine the water potential of a cell. Cell wall, vacuole, filled with aqueous solution and a layer of cytoplasm between cell wall and vacuole. Cell wall is permeable while the rest constitute differentially permeable membrane.

i) Solute Potential (ψ_s) - old term-osmotic pressure: This is due to concentration of dissolved solutes which includes electrolytes and non-electrolytes. Higher the concentration of solutes, lower the water potential, i.e. higher the OP of a solution, lower the water potential. Pure solvent has less osmotic pressure, i.e. solute potential, but solution has more osmotic pressure. Higher the osmotic pressure, higher the DPD or lesser water potential. Thus movement of water will be from lower DPD to higher DPD or higher water

potential to lower water potential, i.e. from pure solvent to solution or dilute solution to concentrated solution. It has negative value (-ve) and is represented in bars units, while OP is represented in atmosphere and has a positive value.

ii) Matrix potential (ψ_m) - old term-imbibitional pressure: Matrix potential refers to the adsorptive affinity of water to colloidal substances and surfaces in plant cells like cell wall and protoplasmic material. Non-vacuolated cells, tissues of dry regions usually have large extent of matrix potential. On the contrary, herbaceous plants having vacuolated cells have negligible value. It is insignificant in osmosis. It is also called imbibitional pressure.

The matrix potential is influenced by hydrophilic colloids. The chemical potential is low at the imbibing surfaces and therefore, water diffuses along a water potential gradient.

ii?) Pressure potential (ψ_p) - old term-hydrostatic pressure/turgor pressure: It is generated due to hydrostatic pressure. It has positive value but is zero in plasmolysed cells and negative in xylem elements at rapid transpiration. Turgor pressure is equal in amount but opposite in direction to the pressure of the cell wall. In plant cell, the turgor pressure is fairly large due to presence of vacuole and rigid cell wall, while this is small in animal cell.

Components of water potential can be derived from DPD formula as follows:

$$\text{DPD} = \text{OP} - \text{TP}$$

$$\text{Water potential} = - \text{osmotic potential} - \text{pressure potential}$$

$$\text{Or, } \psi_w = -\psi_\pi - \psi_p$$

$$\text{Or, } -\psi_w = \psi_\pi + \psi_p$$

Since osmotic potential (ψ_π) depends upon the concentration of solute as well as the amount of water binding matrix (ψ_m) of the solution, osmotic potential is the sum of solute potential and matrix potential.

$$\text{Or, } \psi_\pi = \psi_s + \psi_m$$

Thus, water potential can be finally represented as

$$\psi_w = \psi_s + \psi_m + \psi_p, \quad \psi_m \text{ is negligible for vacuolated cell } (\psi_m = 0)$$

$$\text{Hence, } \psi_w = \psi_s + \psi_p$$

Water potential of pure water is zero, hence solution has negative value.

Water potential is a diagnostic tool in explaining osmosis and turgor pressure phenomena, which are important in the mechanism of water movement. With the help of water potential, one may find the water status in cells and tissues. Water potential is decrease or increase by factors, which decrease or increase relative water vapor. It is reduced by addition of solutes, negative pressures, and reduction in temperature and increased by mechanical pressure as well as increase in temperature.

Leaves of mesophytes have a water potential of -10 bars while those of xerophytes have -15 bars. Rarely does water potential have a positive value (in xylem sap when root pressure develops).

$$1 \text{ bars} = 0.987 \text{ atmosphere} = 10^6 \text{ dynes/cm}^2$$

Soil- Plant - Atmosphere Continuum

Movement of water from the soil through the plant to the atmosphere involves different mechanism of transport.

- In the soil and xylem: Water moves by bulk flow in response to a pressure gradient.
- In Vapour phase, water moves by diffusion till it reaches the outside air, where convection is dominant.
- Across the membrane: Water is transported due to water potential difference across the membranes.

In all of these situations, water moves towards region of low water potential or free energy.

The water potential decreases consistently from the soil to the leaves. The components of the water potential vary at different parts of the pathway e.g., water potential of leaf cell of mesophyll is approximately same with that of neighboring xylem but the components are different.

The dominant component of ψ_w in the xylem is the negative pressure (ψ_p) whereas in the leaf cell (ψ_p) is generally positive. This large difference across the plasma membrane of leaf cells helps in transport of water. Within the leaf cells, water potential is reduced by a high concentration of dissolved solutes low (ψ_s). In the vapour phase we cannot dissect ψ_w into ψ_s and ψ_p , instead the relative humidity is the significant factor determining ψ_w .

Location	Water Potential (ψ_w)	Pressure (ψ_p)	Osmotic Potential (ψ_s)	Gravity (ψ_g)
Outside air	-95.2	--	--	--
Leaf xylem	-0.8	-0.8	-0.1	0.1
Root xylem	-0.6	-0.5	-0.1	0.0

STOMATAL PHYSIOLOGY

Definition: Transpiration is the phenomenon in which excess water is lost in the form of water-vapour from the internal tissues of aerial parts of plants under the influence of sunlight and regulated by the protoplasm.

Depending upon the organ involved, transpiration is of 3 types.

- 1) Stomatal transpiration: It occurs through stomata and is the most predominant one (up to 90-97% of whole transpiration).
- 2) Cuticular transpiration: It occurs through cuticle present in the surface of stem, fruits, flower petals and leaves. It is about 3-9% of the whole.
- 3) Lenticular transpiration: It occurs through lenticels found in woody stems, corky stems and fruits. It is about 1% of total transpiration.

Mechanism of Opening Closing of Stomata: Stomatal movement on the basis of opening may be:

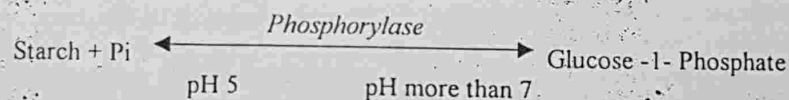
- 1) Photoactive movement: It is directly or indirectly controlled by light. Stomata open by day.
- 2) Scotoactive movement: It is not controlled by light stomata opens at night, which is observed in CAM plants.

(Stomatal movement (opening and closing) of both types depends upon the changes in turgidity of guard cells.) Stomata are open when the guard cells are turgid and close when guard cells are flaccid (During turgidity of guard cells, both walls of guard cells get stretched. Thin outer wall gets more stretched while inner wall gets less stretched, giving a concave or kidney shaped to each guard cell. This results into widening of space, thereby opening the stomata.

(When guard cell loses turgidity, the thick inner walls revert to their original position, causing narrowing and finally closing of stomata.)

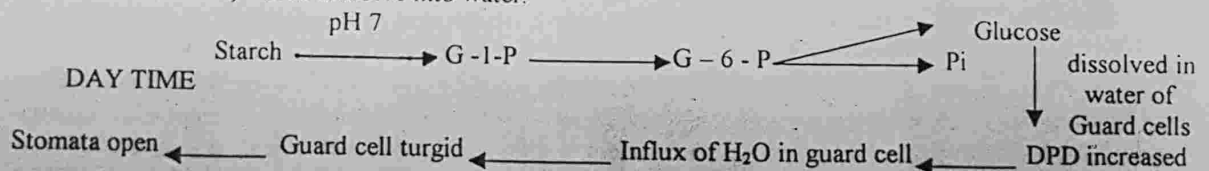
Starch- Sugar hypothesis: This hypothesis was first proposed by Lloyd (1908). The amount of starch in guard cells increases during night which leads to closure of stomata. During daytime, starch content decreases and is converted into sugar leading to opening of stomata. Increase in water soluble sugar by day in guard cells leads to increase in OP and subsequently in DPD in respect to nearby cells, causing endosmosis and turgidity of guard cells favouring opening of stomata. The reverse occurs during closing of stomata.

Vin & Tung in 1948 stated that starch is converted at high pH and in presence of the enzyme *phosphorylase* into Glucose- 1- phosphate and the reverse occurs at low pH.

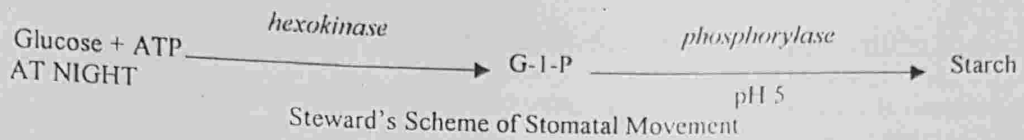


During day time, pH is high so G-1-P is formed, which is water soluble, leading to increase in O.P and D.P.D. As a result, Water is in flux causing turgidity leading to opening of stomata. The reverse occurs during night causing closure of stomata.

Steward (1964) elaborated the above theory by stating that the G-1-P is further converted to G-6-P and then to Glucose & Pi, which dissolve into water.



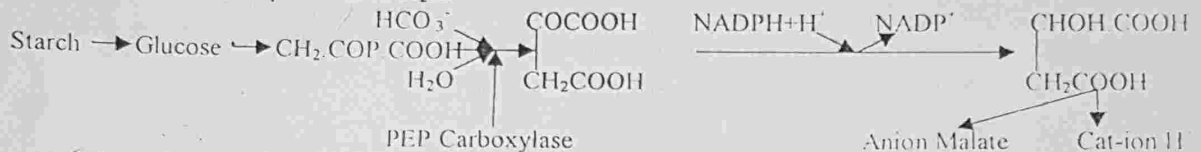
In dark photosynthesis stops, causing, lower in CO₂ concentration & pH. Glucose molecules are converted into G-1-P by *hexokinase* and respiratory ATP. G-1-P is converted into starch.



- Objections: i) Glucose is not detected in guard cells at the time of stomatal opening.
 ii) Starch Sugar inter conversion is too slow but stomatal opening is a fast process.
 iii) Change in CO_2 concentration in the leaf interior can't cause such a wide pH fluctuation.

Theory of K^+ transport and Hormonal Regulation: This theory was proposed by Levitt (1974) and elaborated by Bowhngs. Light induced stomatal opening occurs by the transport of K^+ ions from epidermal or subsidiary cells into the guard cell. Closing is regulated by a hormone.

In light CO_2 concentration goes down due to its utilization in Photosynthesis. Starch is converted to PEP (Phosphoenol Pyruvate) by glycolysis. PEP gets diffused into stoma where it is converted into organic acid by reacting with HCO_3^- in presence of H_2O .



✓ The malic acid dissociates into malate anion and H^+ cat ion in guard cells. H^+ ions are transported to subsidiary cells and K^+ ions are taken into the guard cells in its (H^+ ions) exchange. K^+ ions (cat ions) are balanced by organic anion (malate). Cl^- ions are taken to neutralize K^+ ions. This $\text{H}^+ - \text{K}^+$ ion exchange requires ATP (Supplied by photophosphorylation or respiration). Due to ion exchange O.P increases leading to D.P.D increase in guard cells. Influxions of water into guard cells, lead to turgidity followed by opening of stomata.

✓ In Dark CO_2 accumulation occurs in dark in the guard cells due to stoppage of photosynthesis. ABA in the presence of CO_2 inhibits the K^+ uptake by causing change in diffusion & permeability of guard cells. ABA closes stomata by causing depolarization. Depolarization occurs due to Increase in cytosolic Ca^{+2} and alkalization of cytosol.

✓ ABA + receptor molecule in plasma membrane of guard cells $\rightarrow$ Activation of Ca^{+2} channel proteins and IP_3 molecules (2nd messenger) $\rightarrow$ opening of Ca^{+2} channel $\rightarrow$ efflux of Ca^{+2} from vacuole to cytosol $\rightarrow$ inhibition of K^+ channel proteins stopping K^+ influx $\rightarrow$ Cl^- channel proteins stimulated leading to Cl^- efflux from cytosol $\rightarrow$ Depolarization of plasma membrane & increase in cytosolic pH.

This efflux of K^+ through outward K^+ channels causes loss in turgidity in guard cells causing closure. Anti-transpirant: Certain substances when applied on the plant surface, retards their transpiration. These are called Anti-transpirants.

Some anti-transpirants like colour less plastics, silicon oils and low viscosity waxes which when sprayed on leaves form a thin film which is impermeable to water but not to CO_2 or O_2 .

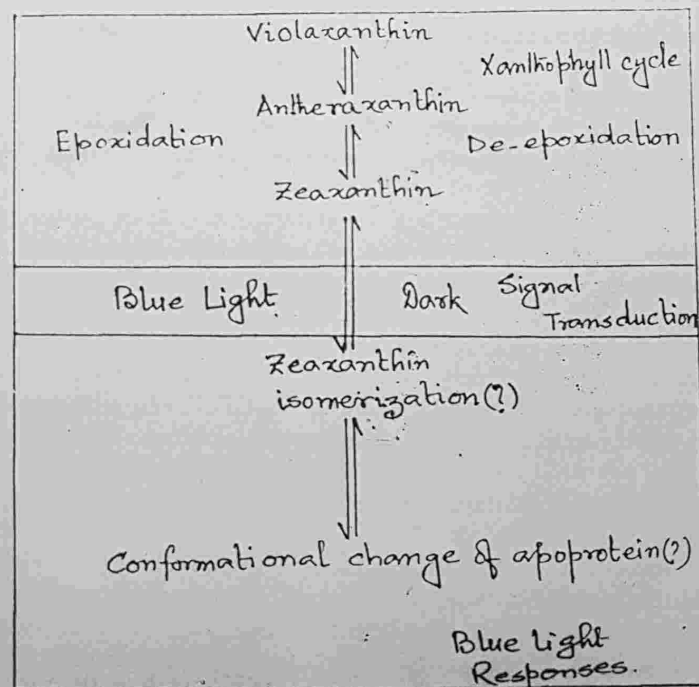
Some anti-transpirants consists of substances which when sprayed on leaves cause partial closure of stomata. These substances in proper concentration cause very little adverse effect on plant tissues. Foliar spray with 10^{-4} M conc. of phenyl mercuric acetate closes stomata for a period of 2 weeks or more. ABA also acts as an anti-transpirant causing closure of stomata.

CO_2 in an increased concentration from a usual 0.03% to 0.05% acts as an anti-transpirant causing partial closure of stomata, further increase however close the stomata completely.

Anti-transpirants can be utilized in crop production e.g. cultivation of high priced crops, in seedling transplantation in nurseries or in horticultural practices or for laboratory works.

✓ Role of Blue Light: Blue Light stimulated stomata movements are driven by blue light dependent changes in the osmoregulation of guard cells. Blue light stimulates an H^+ - *ATPase* at the guard cells plasma membrane, & the resulting pumping of protons across the membrane generates an electro chemical-potential gradient that provides a driving force for ion uptake. Blue light also stimulates starch degradation & malate biosynthesis. Solute accumulation within the guard cells leads to stomatal opening.

The chloroplast carotenoid, zeaxanthin has been implicated in this blue light photoreception in guard cells. The *Arabidopsis* mutant npq1 has a genetic lesion in the enzyme that converts violaxanthin into zeaxanthin (Niyogi et al, 1998). Because, of this mutation neither mesophyll, nor guard cell chloroplast of npq1 accumulate zeaxanthin. Availability of this mutant made it possible to test the zeaxanthin hypothesis with guard cells in which zeaxanthin accumulation is genetically blocked. Blue light stimulated stomata opening is blocked if zeaxanthin accumulation in guard cells is prevented by genetic or biochemical means. Manipulation of zeaxanthin content in guard cells makes it possible to regulate their response to blue light. The signal transduction cascade for the blue light response of guard cells comprises blue light perception in the guard cell chloroplast, transduction of the blue light signal across the chloroplast envelope, activation of the H^+ - *ATPase*, turgor build up & stomatal opening. It is observed in phot1 or phot2 *Arabidopsis* mutant singly and exhibit a specific blue light response.



Postulated cascade of events leading to stomatal opening induced by blue light, through xanthophyll cycle. (after Jabott and Zeiger, 1998)